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ABSTRACT

We have studied spin observables in the three-body break-up reaction in deuteron–deuteron scattering in the phase-space regime that corresponds to the quasi-free deuteron–proton scattering process with the neutron as spectator. The data are compared to measurements of the elastic deuteron–proton scattering process and state-of-the-art Faddeev calculations. The results for iT_{11} and T_{22} for the quasi-free scattering data agree very well with previously published elastic-scattering data. A significant discrepancy is found for T_{20}, which could point to a break-down of the quasi-free assumption.

1. Introduction

Understanding the exact nature of the nuclear force is one of the long-standing questions in nuclear physics. In 1935, Yukawa successfully described the pair-wise nucleon–nucleon (NN) interaction as an exchange of a boson [1]. Current NN models are mainly based on Yukawa's idea and provide an excellent description of the high-quality data base of proton–proton and neutron–proton scattering [2–6] and of the properties of the deuteron.

Although much has been learned about the interaction between two nucleons, it remains questionable whether this knowledge is sufficient to describe the interaction between more than two nucleons. Already for the simplest three-nucleon system, the triton, an exact solution of the three-nucleon Faddeev equations employing two-nucleon forces (2NFs) underestimates the experimental binding energy [3], showing that 2NFs are not sufficient to describe the three-nucleon system accurately. In a three-nucleon system, the interaction between two of the nucleons may be influenced by the presence of the third nucleon. This extra effect comes from a force which is beyond the two-nucleon interaction and will be referred to as a three-nucleon force in this Letter (3NF). Most of the current models for the 3NF are based on a refined version of Fujita–Miyazawa's 3NF model [7], in which a 2π-exchange mechanism is incorporated by an intermediate Δ excitation of one of the nucleons [8,9]. More recently, NN and three-nucleon potentials have become available which are derived from the basic symmetry properties of the fundamental theory of Quantum Chromodynamics (QCD) [10–13]. These so-called chiral-perturbation (χPT) models systematically construct a potential from a low-energy

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expansion of the most general Lagrangian with only the Goldstone bosons, e.g. pions, as exchange particles.

A comparison between experimental data obtained in nucleon–deuteron scattering for the reactions involving more than two nucleons with the corresponding theoretical predictions reveals serious discrepancies, specially in the case of spin observables [14–46]. This implies that the behavior of the systems with more than two nucleons is not completely understood and hints towards a deficiency in the spin structure of 3NFs. Therefore, theoretical calculations for these systems need improvements which could be guided by more experimental data. In particular, channels and observables that show a large sensitivity to the effects of 3NFs are the most advantageous. A detailed review article on our present theoretical and experimental understanding of 3NFs and its implications in the field of nuclear physics can be found in Ref. [47].

Naively one might expect that the 3NF effects increase in the four-nucleon system by the argument that the number of three-nucleon combinations with respect to two-nucleon combinations gets larger as one increases the number of nucleons. For large nuclei, however, the saturation of 3NF effects sets in very quickly. The increase in sensitivity to 3NF effects with increasing the number of nucleons is supported by a comparison between predictions and data for the binding energies of light nuclei [48]. The predictions come from a Green's function Monte Carlo calculation based on the Argonne V18 [4] NN interaction (AV18) and the Illinois-2 (IL2) 3NF [49,50]. While a calculation which only includes the AV18 NN potential deviates significantly from the experimental results, a calculation which includes as well a 3NF compares much better to the data. Note that the effect of the 3NF on the binding energy for the triton is $\sim$0.5 MeV, whereas the effect increases significantly for the four-nucleon system, ^{4}He, to $\sim$4 MeV. For heavier nuclei, even adding the 3NF as modeled in the present calculations, is not enough to resolve the discrepancies between the theoretical predictions and the measurements. One might argue that the discrepancies for the binding energies of the heavier nuclei stem from four-nucleon force (4NF) effects. These higher-order many-body potentials are, however, predicted by χPT approaches [10–13] to be negligible compared to 3NF effects. Therefore, it is very unlikely that the large discrepancies can be explained by a missing 4NF or even higher-order nuclear-force effects. This is another evidence which shows that the behavior of the systems with more than two nucleons is not understood yet.

This Letter presents the results of a recent measurement of spin observables in the three-body break-up reaction in deuteron–deuteron scattering, $\vec{d} + d \longrightarrow d + p + n$. We are particularly interested in the regions of phase space for which the neutron acts as a spectator particle. These data can directly be compared to spin observables in the elastic scattering process, $\vec{d} + p \longrightarrow d + p$, which are measured using the same setup and with the same beam by replacing the liquid deuterium target with a solid (CH_2) target containing hydrogen atoms. Furthermore, the data can be interpreted using ab-initio Faddeev calculations that are based upon modern two- and three-nucleon potentials. The feasibility of identifying and measuring spin observables in the three-body break-up reaction in deuteron–deuteron scattering has been reported recently in Refs. [51,52].

2. Experiments

We performed two scattering experiments at KVI using the Big Instrument for Nuclear-polarization Analysis (BINA) [51]. A large part of the setup, in particularly the wall part, consisted of elements that were used by the former SALAD detection system [53]. The polarized beam of deuterons for both experiments was produced by a polarized ion source (POLIS) [54,55] at KVI and was accelerated by AGOR (Accélérateur Groningen ORsay). In the first experiment, a polarized beam of deuterons with a kinetic energy of 65 MeV/nucleon was impinged on a liquid deuterium target [56]. The elastic channel, the neutron transfer channel, and break-up channels leading to three- and four-body final states were uniquely identified using the information on the energies of the outgoing particles, their scattering angles, and their time-of-flight (TOF) [51, 52]. We note that the three-body break-up channel in deuteron–deuteron scattering is extremely rich in phase space even more than the $\vec{p} + d$ reaction since its final state is composed of non-identical particles. These data contain a wealth of information that can be exploited to study many-body forces. The measured differential cross sections, vector- and tensor-analyzing powers for a large number of kinematical configurations of the three-body break-up reaction are reported in Ref. [51].

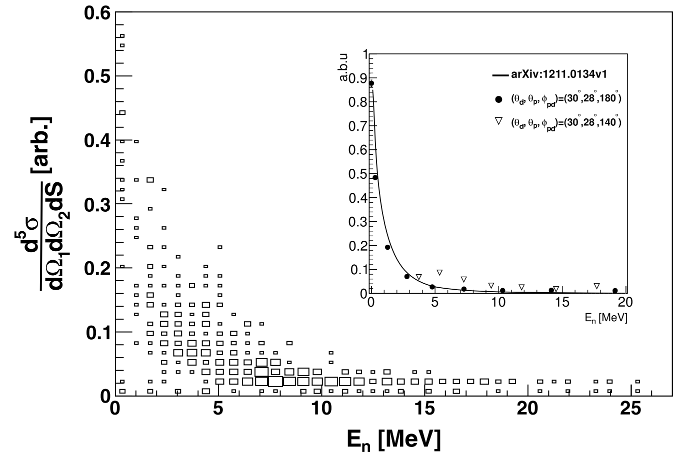

Fig. 1. Relative cross sections for all of the analyzed configurations of the three-body break-up reaction in $\vec{d} + d$ scattering as a function of the outgoing neutron energy. The size of each box corresponds to the number of configurations that fall in that bin. Inset: The reconstructed neutron-energy distribution for a few selected configurations. The solid line represents the expected energy distribution (normalized to the data) of the neutron for the quasi-free scattering process.

In the second experiment, the elastic reaction $^1\text{H}(\vec{d}, dp)$ was studied using a deuteron-beam energy of 65 MeV/nucleon and a solid CH_2 target. We made use of this reaction to check the systematic uncertainties and also to measure the polarization of the beam of deuterons [52]. The vector and tensor polarizations of the beam was determined by combining measurements of the azimuthal asymmetries of the reaction yield and the published data for iT_{11} and T_{22}. The polarization of the deuteron beam was measured as well in the low-energy beam line with a Lamb-Shift Polarimeter (LSP) [57]. The polarization values obtained with the LSP were found to be in an excellent agreement with the ones measured with BINA [52]. For a part of phase space in the $\vec{d}p$ elastic reaction in which both particles are scattered to the forward angles, data on T_{20} were compared with the results of the three-body reaction in the deuteron–deuteron scattering.

We were interested in studying the quasi-free process with the neutron as spectator, e.g. $\vec{d} + d \longrightarrow d + p + n_{\text{spec}}$ which can be compared to the elastic reaction $\vec{d} + p \longrightarrow d + p$. For each coincidence event, we measured the scattering angles and energies of the outgoing deuteron and proton. Using the known beam energy, we calculated the angle and energy of the unobserved neutron. Fig. 1 represents the cross sections in arbitrary units obtained for all analyzed configurations of the first experiment as a function of the energy of the outgoing neutron, E_n. Each configuration corresponds to a small region in the scattering angles of the deuteron and proton, their relative azimuthal angle, and their relative energy represented by the variable S as explained in detail in Ref. [52].

Table 1
The selected configurations in the three-body break-up reaction for which the neutron energy, $E_n < 0.3$ MeV. These configurations were identified as the quasi-elastic $d + p \to d + p$ reaction. The corresponding center-of-mass angle, $\theta_{c.m.}$, is indicated as well.

θ_d [deg]	θ_p [deg]	ϕ_{pd} [deg]	S [MeV]	$\theta_{c.m.}$ [deg]
28 ± 1	20 ± 1	180 ± 5	230 ± 10	139.0 ± 1
29 ± 1	22 ± 1	180 ± 5	220 ± 10	134.8 ± 1
29 ± 1	24 ± 1	180 ± 5	220 ± 10	130.7 ± 1
30 ± 1	26 ± 1	180 ± 5	220 ± 10	126.6 ± 1
30 ± 1	28 ± 1	180 ± 5	210 ± 10	122.6 ± 1

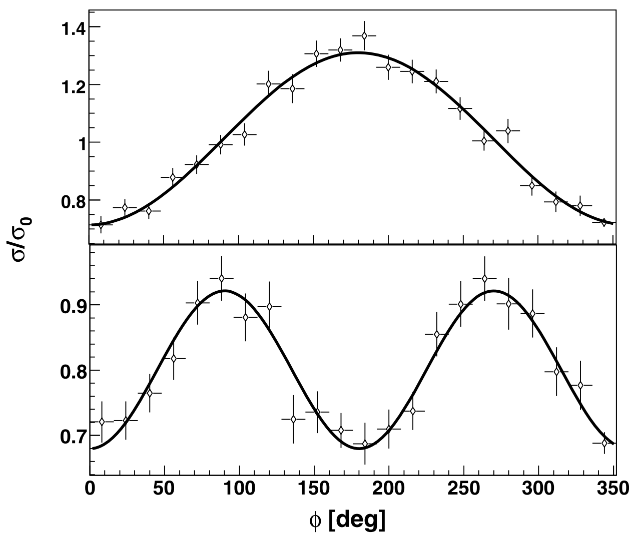

Fig. 2. The ratio of the spin-dependent cross section to the unpolarized one for a pure vector-polarized deuteron beam (top panel) and a pure tensor-polarized deuteron beam (bottom panel) for ($\theta_p = 28°$, $\theta_d = 30°$, $\phi_{pd} = 180°$, $S = 210$ MeV).

The five-fold differential cross section is at its maximum when the energy of the neutron is very small. The reconstructed energy distribution of the missing neutron for various configurations have been compared with the expected energy distribution of the neutron derived from the deuteron wave function. In this study, illustrated in the inset of Fig. 1, we were particularly interested in comparing those configurations that were close to the kinematics of the quasi-free elastic reaction with the neutron as spectator. For the angular conditions that are summarized in Table 1, we found that the energy distributions of the reconstructed missing neutron match very well the expected energy distribution of the neutron from the deuteron wave function, thereby validating the quasi-free assumption. The filled circles in the inset of Fig. 1 show the result for one of these configurations and the data are compared to the expected neutron-energy distribution (solid line). We note that neutron-energy distributions peak strongly towards very low momenta, a feature which is absent for other configurations that are far from the kinematics for the elastic channel (see for example the open triangles in the inset of Fig. 1). To minimize the contamination from final-state interactions, an additional constraint on the value of S was made to limit the energy of the neutron, E_n, to less than 0.3 MeV. This corresponds to a momentum of the neutron of less than 23 MeV/c. Table 1 gives a complete overview of the few configurations that were used in the further analysis with their corresponding center-of-mass angle, $\theta_{c.m.}$, of the quasi-elastic $d + p \to d + p$ reaction. In our further discussion, we label this region as the quasi-free deuteron–proton scattering process with the neutron acting as a spectator particle.

3. Results

The spin observables of the quasi-free scattering process were obtained by studying the cross section dependence on the azimuthal angle of the event. More precisely, when the quantization axis is perpendicular to the beam direction, the vector- and tensor-analyzing powers can be extracted using the following cross-section relation:

$$\sigma(\theta,\phi) = \sigma_0(\theta)\left[1 + \sqrt{3}p_Z iT_{11}(\theta)\cos\phi - \frac{1}{\sqrt{8}}p_{ZZ}T_{20}(\theta) - \frac{\sqrt{3}}{2}p_{ZZ}T_{22}(\theta)\cos 2\phi\right], \tag{1}$$

where θ and ϕ are the polar and azimuthal angles, iT_{11} is the vector-analyzing power and T_{22} and T_{20} are tensor-analyzing powers. The quantity σ_0 refers to the unpolarized cross section which is obtained with an unpolarized deuteron beam. The vector and tensor beam polarizations, p_Z and p_{ZZ}, respectively, were obtained from a polarization measurement in the low-energy beam line using a Lamb-Shift Polarimeter (LSP) [57] combined with a polarization measurement in the high-energy beam line with BINA using the elastic $\vec{d} + p \to d + p$ reaction. The final polarization values were extracted from a linear fit through the measured values with BINA and LSP [52]. Fig. 2 depicts the ratio between the spin-dependent cross section and the cross section for the unpolarized beam normalized to each other as a function of the azimuthal angle of scattered deuteron, ϕ, for a pure vector-polarized deuteron beam (top panel) and a pure tensor-polarized deuteron beam (bottom panel) for one of the five configurations, namely ($\theta_p = 28°$, $\theta_d = 30°$, $\phi_{dp} = 180°$, $S = 210$ MeV). The symbols θ_p and θ_d are the polar angle of proton and deuteron in the final state, respectively and $\phi_{dp} = \phi_d - \phi_p$ is the relative azimuthal angle of proton and deuteron. The data are fitted to obtain the vector- and tensor-analyzing powers. Note that the amplitude of the $\cos\phi$ modulation in the top panel equals $\sqrt{3}p_Z iT_{11}$ and that of the $\cos 2\phi$ modulation in the lower panel equals $-\frac{\sqrt{3}}{2}p_{ZZ}T_{22}$. The offset from 1 in the lower panel equals $-\frac{1}{\sqrt{8}}p_{ZZ}T_{20}$. The results of the fit are shown as solid curves and are in an excellent agreement with the data (χ^2/n.d.f. $\simeq 1$).

The results of our measurements of the analyzing powers in the quasi-free limit are shown in Fig. 3 by filled squares and compared with $\vec{d}p$ elastic-scattering data from Ref. [39] (open circles). The results described in this Letter are a finalized version of preliminary data that were presented at the 19th International Spin Physics Symposium, SPIN2010 [58]. We also compare our break-up data for T_{20} with data we obtained from the elastic-scattering process using a solid target (filled circles). The errors shown on the data points are statistical only and the horizontal dark gray bands at the top of the panels represent the systematic uncertainty (2σ) for every data point. The systematic uncertainty for the analyzing power mainly stems from the uncertainty in the measurement of the beam polarization via elastic scattering and to a much lesser extent from the error of the beam-current correction in the analysis of the T_{20} [51]. The angular bin size in the present measurement is 2°. The results of the iT_{11} and T_{22} for the quasi-free scattering data agree very well with the previously published $\vec{d}p$ elastic-scattering data. However, we observe significant discrepancies for T_{20} of the quasi-free results with the elastic channel.

The dark gray bands in Fig. 3 correspond to calculations including only two-nucleon potentials [2–6]. The light gray bands represent calculations including an additional Tucson–Melbourne TM′ three-body force [8]. The solid curves correspond to results of a Faddeev calculation using the AV18 two-nucleon potential [4]

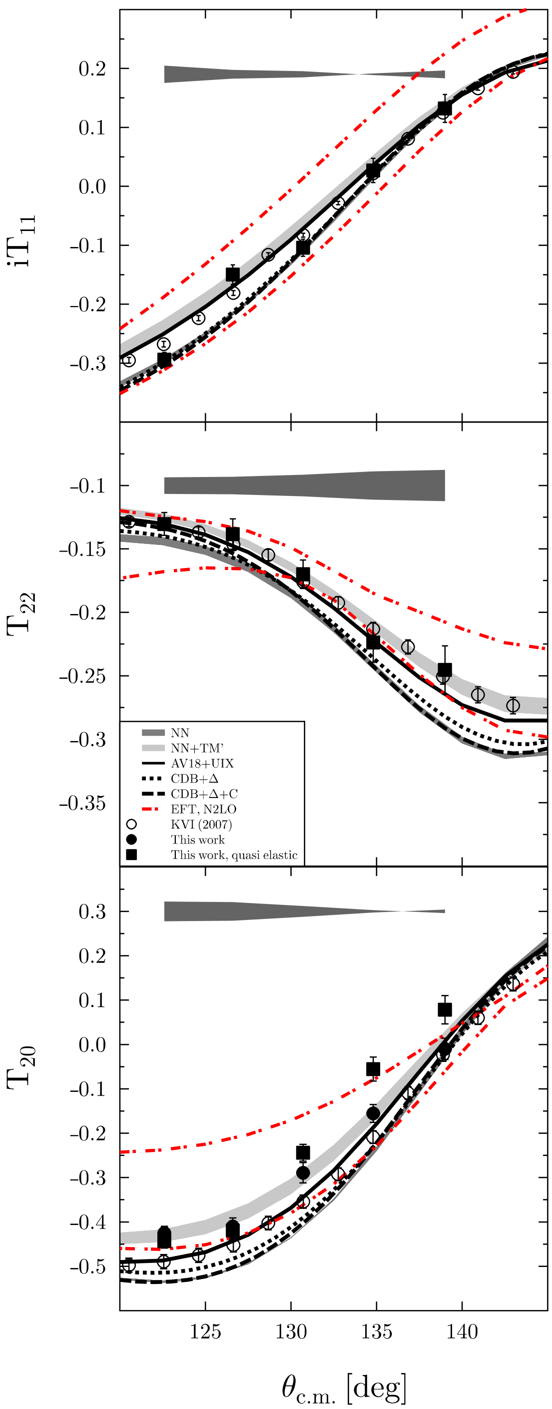

Fig. 3. The vector- and tensor-analyzing powers of the quasi-free deuteron–proton scattering process in deuteron–deuteron three-body break-up. The data of this experiment are shown as filled squares and are compared with published $\vec{d}p$ elastic-scattering data taken at KVI [39]. The obtained data for T_{20} from the elastic-scattering process using a solid target are shown as filled circles. The horizontal dark gray bands at the top of the panels represent the systematic uncertainty (2σ) for every data point. The dark gray bands correspond to calculations including only two-nucleon potentials. The light gray bands represent calculations including an additional Tucson–Melbourne TM′ three-body force. The solid curves correspond to results of a Faddeev calculation using the AV18 two-nucleon potential combined with the Urbana-Illinois X (UIX) three-body potential. The dotted curve represents the results of a coupled-channel calculation (CDB + Δ). The dashed curve represents the results of a CDB + Δ calculation including the Coulomb force. The upper and lower dot-dashed (red in the web version) curves in each panel represent the results of an N^{2}LO calculation based on an effective field theory for the elastic $\vec{d}+p$ channel [61]. The differences between the two curves represent the uncertainty of the calculation.

combined with the Urbana-Illinois X (UIX) three-body potential [59]. Not that adding the three-nucleon effects to the two-body potentials brings calculations results closer to the data points. The dotted curve represents the results of a coupled-channel calculation based on an extended CD-Bonn potential incorporating a virtual Δ excitation [9]. The dashed curve represents the results of a similar calculation, but with the inclusion of the Coulomb force [60]. The upper and lower dot-dashed (red) curves in each panel represent the results of a N^{2}LO calculation based on an effective field theory (EFT) for the elastic $\vec{d}+p$ channel at a kinetic energy of 65 MeV/nucleon [61]. The bands represent the amount of the residual cut-off dependence which cannot be compensated since the expansions are truncated at N^{2}LO or N^{2}LO. The precision of the calculations based on an EFT is not conclusive when comparing to the much more precise experimental data. In general, we observe that the potential calculations including a TM′ 3NF describe the elastic-scattering data for iT_{11}, T_{22}, and T_{20} well. The coupled-channel calculation appears to be less accurate in describing the experimental data, which could point to missing 3NF effects in their approach. Note that the predictions of all phenomenological approaches deviate significantly with our quasi-free results for T_{20} at large scattering angles.

4. Conclusions

The main goal of the experiment described in this Letter was to study spin observables in the three-body break-up channel in deuteron–deuteron scattering at the limit of the quasi-free scattering process $\vec{d}+d \longrightarrow d+p+n_{\mathrm{spec}}$. This reaction manifests itself when the transferred momentum to the neutron is very small and hence the neutron plays a role as a spectator particle. For this part of the phase space, the three-body break-up reaction in deuteron–deuteron scattering is similar to the elastic $\vec{d}p$ scattering reaction. Although, the four-nucleon scattering process lacks rigorous theoretical calculations, we believe that this part of the phase space can be tested by a comparison with data and calculations in the three-nucleon sector. The analysis of the data reported in this Letter shows that the measured vector and tensor analyzing powers of the three-body break-up reaction in deuteron–deuteron scattering at 65 MeV/nucleon agree well with previously published analyzing powers of the elastic $\vec{d}p$ channel. Only for the tensor analyzing power, T_{20}, at large scattering angles significant discrepancies are observed between previously published results and $\vec{d}p$ elastic data taken with the same setup, BINA, using a CH_2 target. These deficiencies might be attributed to the role of final-state interactions and, therefore, to the limited applicability of the quasi-free assumption, especially for the tensor component of the interaction.

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References

[1] H. Yukawa, Proc. Phys. Math. Soc. Jpn. 17 (1935) 48.
[2] V.G.J. Stoks, R.A.M. Klomp, C.P.F. Terheggen, J.J. de Swart, Phys. Rev. C 49 (1994) 2950.
[3] R.B. Wiringa, R.A. Smith, T.L. Ainsworth, Phys. Rev. C 29 (1984) 1207.
[4] R.B. Wiringa, V.G.J. Stoks, R. Schiavilla, Phys. Rev. C 51 (1995) 38.
[5] M.M. Nagels, T.A. Rijken, J.J. de Swart, Phys. Rev. D 17 (1978) 768.
[6] R. Machleidt, K. Holinde, Ch. Elster, Phys. Rep. 149 (1978) 1.
[7] J. Fujita, H. Miyazawa, Prog. Theor. Phys. 17 (1957) 360.
[8] S.A. Coon and, H.K. Han, Few-Body Syst. 30 (2001) 131.
[9] A. Deltuva, R. Machleidt, P.U. Sauer, Phys. Rev. C 68 (2003) 024005.
[10] E. Epelbaum, et al., Nucl. Phys. A 637 (1988) 107.
[11] U. van Kolck, Phys. Rev. C 49 (1994) 2932.
[12] E. Epelbaum, et al., Nucl. Phys. A 671 (2000) 295.
[13] E. Epelbaum, et al., Phys. Rev. C 65 (2002) 044001.
[14] H. Postam, R. Wilson, Phys. Rev. 121 (1961) 1129.
[15] A. Michalowicz, M. Poulet, Nucl. Phys. 88 (1966) 33.
[16] R.E. Adelerger, N. Brown, Phys. Rev. D 5 (1972) 2139.
[17] H. Shimizu, et al., Nucl. Phys. A 382 (1982) 242.
[18] H. Sakai, et al., Phys. Rev. Lett. 84 (2000) 5288.
[19] J.G. Messchendorp, et al., Phys. Lett. B 481 (2000) 171.
[20] R. Bieber, et al., Phys. Rev. Lett. 84 (2000) 606.
[21] K. Ermisch, et al., Phys. Rev. Lett. 86 (2001) 5862.
[22] R.V. Cadman, et al., Phys. Rev. Lett. 86 (2001) 967.
[23] J. Kuroś-Żołnierczuk, et al., Phys. Rev. C 66 (2002) 024004.
[24] K. Sekiguchi, et al., Phys. Rev. C 65 (2002) 034003.
[25] K. Ermisch, et al., Phys. Rev. C 68 (2003) 051001.
[26] H. Hatanaka, et al., Eur. Phys. J. A 18 (2003) 293.
[27] H. Hatanaka, et al., Phys. Rev. C 66 (2003) 044002.
[28] H.O. Meyer, et al., Phys. Rev. Lett. 93 (2004) 112502.
[29] K. Sekiguchi, et al., Phys. Rev. C 70 (2004) 014001.
[30] St. Kistryn, et al., Phys. Rev. C 72 (2005) 044006.
[31] K. Ermisch, et al., Phys. Rev. C 71 (2005) 064004.
[32] A.A. Mehmandoost-Khajeh-Dad, et al., Phys. Lett. B 617 (2005) 18.
[33] K. Sekiguchi, et al., Phys. Rev. Lett. 95 (2005) 162301.
[34] B.V. Przewoski, et al., Phys. Rev. C 74 (2006) 064003.
[35] S. Kistryn, et al., Phys. Lett. B 641 (2006) 23.
[36] A. Biegun, et al., Acta Phys. Pol. B 371 (2006) 213.
[37] H. Mardanpour, et al., Eur. Phys. J. A 31 (2007) 383.
[38] H. Mardanpour, et al., Phys. Lett. B 687 (2007) 149.
[39] E. Stephan, et al., Phys. Rev. C 76 (2007) 057001.
[40] A. Ramazani-Moghaddam-Arani, et al., Few-Body Syst. 44 (2008) 27.
[41] A. Ramazani-Moghaddam-Arani, et al., Phys. Rev. C 78 (2008) 014006.
[42] E. Stephan, et al., Eur. Phys. J. A 42 (2009) 13.
[43] H. Mardanpour, PhD thesis, University of Groningen, 2008.
[44] M. Eslami-Kalantari, PhD thesis, University of Groningen, 2009.
[45] E. Stephan, et al., Phys. Rev. C 82 (2010) 014003.
[46] I. Ciepał, et al., Phys. Rev. C 85 (2012) 017001.
[47] N. Kalantar-Nayestanaki, et al., Rep. Prog. Phys. 75 (2012) 016301.
[48] S.C. Pieper, V.R. Pandharipande, R.B. Wiringa, J. Wiringa, H. Carlson, Phys. Rev. C 64 (2001) 014001.
[49] V.R. Pandharipande, B.S. Pudliner, H. Carlson, R.B. Wiringa, Phys. Rev. C 74 (1995) 4396.
[50] S.G. Pieper, et al., Nucl. Phys. A 458 (1986) 287.
[51] A. Ramazani-Moghaddam-Arani, PhD thesis, University of Groningen, 2009.
[52] A. Ramazani-Moghaddam-Arani, et al., Phys. Rev. C 83 (2011) 024002.
[53] N. Kalantar-Nayestanaki, et al., Nucl. Instrum. Methods A 444 (2000) 591.
[54] L. Friedrich, E. Huttel, R. Kremers, A.G. Drentje, The Polarized Ion Source for the AGOR Facility, World Scientific, Singapore, 1995, p. 198.
[55] H.R. Kremers, A.G. Drentje, AIP Conf. Proc. 241 (1997) 507.
[56] N. Kalantar-Nayestanaki, J. Mulder, J. Zijlstra, Nucl. Instrum. Methods Phys. Res. A 417 (1998) 215.
[57] H.R. Kremers, J.P.M. Beijers, N. Kalantar-Nayestanaki, T.B. Clegg, Nucl. Instrum. Methods Phys. Res. A 516 (2004) 209.
[58] A. Ramazani-Moghaddam-Arani, et al., J. Phys., Conf. Ser. 295 (2011) 012120.
[59] B.S. Pudliner, V.R. Pandharipande, H. Carlson, S.C. Pieper, R.B. Wiringa, Phys. Rev. C 56 (1997) 1720.
[60] A. Deltuva, A.C. Fonseca, P.U. Sauer, Phys. Rev. C 73 (2006) 057001.
[61] E. Epelbaum, private communications, 2013.